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DAMPED SUPERCONDUCTING COIL SYSTEM HAVING A MULTITURN, PLANAR GEOMETRY SUPERCONDUCTING COIL AND SHUNT RESISTORS ELECTRICALLY CONNECTING SUCCESSIVE COIL TURNS

This application claims the benefit of U.S. Provisional Pat. Application No. 60/055,564 entitled, APPARATUS AND METHODS FOR DAMPING COIL RESONANCES IN PLANAR GEOMETRY SQUIDS, filed on Aug. 13, 1997.

This invention was made with Government support awarded by the National Institute of Standards and Technology under Grant Number 40RNB7B0040. The Government may have certain rights in this invention.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to planar geometry, multi-turn superconducting coils used with a ground plane, and more particularly to apparatus and methods for reducing resonances in such coils.

2. Description of the Prior Art

One of the basic circuit elements of superconducting electronic devices is the inductor. In order to obtain useful values of inductance, multiple windings, or turns, of the inductor coil are often required. Moreover, a basic method of fabricating superconducting electronic devices is thin film deposition and patterning, resulting in the widespread use of planar geometry spiral inductors in practical circuit design. Such nominally spiral coils may be of any symmetry (square, circular, octagonal, etc.). In those situations where planar spiral inductor coils are implemented in conjunction with a ground plane (particularly a superconducting ground plane), stray capacitance between the coil and the ground plane results in an inductive/capacitive resonant circuit with very low damping ("high Q"). Resonance induced changes in the impedance of either the coil or the ground plane at the resonance frequency or frequencies often unfavorably influence the operation of devices incorporating either of the two elements, and therefore damping of these resonances is desirable. The most common (though not exclusive) example of this situation is the input coil to a superconducting quantum interference device (SQUID).

Current technology for SQUID fabrication uses a planar fabrication process to create a washer geometry ground plane whose purpose is to focus magnetic flux from an input inductor or coil to the SQUID body; the ground plane often in fact forms the SQUID body. This geometry was developed by Jaycox and Ketchen (see, for example, "Planar coupling scheme for ultra low noise dc SQUIDS," J. M. Jaycox and M. B. Ketchen, IEEE Trans. Magn., vol. MAG-17, pp. 400-403, January 1981). This geometry results in an inductive-capacitive resonant circuit as discussed above. The resulting resonances distort the output characteristics of the SQUID and introduce electronic noise. Both of these consequences degrade SQUID performance.

FIGS. 1 and 2 (prior art) show a conventional planar SQUID 100, including a multiturn input coil 104 which couples external signals to the SQUID via SQUID washer 102. FIG. 1 is a simplified top view of the device, while FIG. 2 is a schematic. A conventional dc SQUID 100 is formed with a loop of superconducting material (washer 102) interrupted by two Josephson tunnel junctions 106. Josephson junctions 106 are shunted with resistors 112 to remove hysteresis as necessary. In operation, SQUID 100 is biased with a constant current, I_b 130. When a current, I_r 126 passes

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through input coil 104, it causes a magnetic field which modifies the current flow in washer 102, resulting in a change in the voltage across Josephson junctions 106 and the SQUID as a whole. Thus, the measured voltage (V) 124 across the SQUID is related in a predictable way to the current flowing in coil 104, and can be used to determine the current flowing in coil 104. This voltage can be measured by external circuitry.

However, high frequency currents which develop within Josephson junctions 106 cause resonances to develop in coil 104, which cause voltage 124 to lock onto certain values, causing the relation between the value of current 126 introduced into coil 104 to become nonlinear. As a result of the nonlinearity, the SQUID is not as useful as it could be.

Techniques in the prior art which have been used to reduce the effects of resonances have met with limited success. Returning to FIG. 1, these include an external coil shunt 108, a washer shunt 110, overdamped junction shunts 112, and/or coil/washer shunt 114. In the cases of external coil shunt 108, washer shunt 110, and coil/washer shunt 114, both resistive and resistive/capacitive networks have served as the shunting element.

All of the previous methods of damping resonances in planar geometry superconducting coils have attempted to damp the resonance of the coil as a whole. A need remains in the art for improved apparatus and methods for damping resonances in planar geometry superconducting coils.

SUMMARY

It is an object of the present invention to provide improved apparatus and methods for damping resonances in planar geometry superconducting coils. In order to meet this object, an internal damping resistor is applied across the windings of the coil. Thus resistive damping is added to each turn of the coil.

A damped superconductor coil according to the present invention comprises a planar geometry multiturn superconducting coil and an intracoil shunt connecting a plurality of turns of the coil with resistors.

An electrical ground plane is disposed parallel and proximate to the coil. Generally, the electrical ground plane consists of a superconductive material and forms at least one hole, which concentrates magnetic field lines from the coil to the hole. The ground plane may also form a gap extending from the hole to the edge of the ground plane to admit changing magnetic flux.

The coil may comprise a signal coil or a modulation coil of a superconducting quantum interference device (SQUID), an inductor in a filter, or a winding in a transformer.

The shunt may comprise a planar-film resistor which extends along a radius of the coil, or along more than one radius of the coil.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a conventional planar geometry coupled dc superconducting quantum interference device (SQUID), with prior art damping techniques applied.

FIG. 2 shows a schematic diagram of the SQUID of FIG. 1.

FIG. 3 shows a planar geometry coupled dc SQUID having improved coil damping, according to the present invention.

FIG. 4 shows a schematic diagram of the planar geometry coupled SQUID having improved coil damping of FIG. 3.